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EBRA MUSSELS

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Feasibility of Preventing Further Invasion of the Zebra Mussel into the Western United States

Feasibility of Preventing Further Invasion of the Zebra Mussel into the Western United States

Harold Tyus[1], William P. Dwyer[2],
and Sharon Whitmore[3]

U.S. Fish and Wildlife Service

❶ Mountain-Prairie Region
Denver Federal Center,
Denver CO 80225

❷ Bozeman Fish Technology Center,
Bozeman, MT 59715

❸ Missouri River Coordinator's Office,
Pierre, SD 57501-5408

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EXECUTIVE SUMMARY

Introduced in North America in 1986, the exotic zebra mussel, *Dreissena polymorpha*, has quickly spread in the Great Lakes region and Eastern United States. This aquatic nuisance species is expanding its western range, and is a threat to Western aquatic ecosystems and water management facilities. Prevention programs in the East have not developed quickly enough to effectively reduce the spread of this species, and no programs have been developed to reduce or limit its invasion into the West.

Unlike native North American freshwater mussels, the zebra mussel has a free floating, planktonic larva that has aided in its rapid spread by water currents into downstream areas. These planktonic larvae can not move against an upstream gradient, and this will limit their ability to spread further west. In addition, spread of the zebra mussel in the Western United States to, and across, the North American Continental Divide will require its transport across long distances in an arid climate. Mussels attached to boats and other movable equipment will be subjected to desiccation over a long time period. Thus, natural conditions will assist in limiting further western spread and presumably provide the first opportunity to slow or halt the continuing spread of this species across the continent.

In addition to constraints placed on zebra mussel invasion by climate and geography, it may be possible to use

existing Federal and State laws and regulations to reduce or halt its spread to new areas. New partnerships between Federal, State, and other agencies also could be very effective in combating this, and other harmful nonindigenous species. Although an effective public awareness program for the zebra mussel does not presently exist in the West, concerned citizens and citizens groups could play an important and effective role in reducing western transport of the species.

The Fish and Wildlife Service (Service) can take a lead role in combating the spread of the zebra mussel and other nuisance species by encouraging and organizing efforts in the West. First steps would be to: (1) establish and fund Nonindigenous Species/Zebra Mussel Coordinators in Regions 1, 2, and 6 to provide the focal point for the Service effort; (2) develop and implement a zebra mussel action plan that further refines and adds to the recommendations of this report; (3) finalize an existing Draft Memorandum of Understanding with the Bureau of Reclamation on nonindigenous species, and work with that agency, and others, to further develop prevention and control measures; (4) work with State governments and other agencies and organizations to develop similar agreements and encourage them to develop in-house capabilities; (5) develop and activate effective information and education programs; (6) perform risk assessments for Service facilities, programs, and sensitive western ecosystems that may be at risk; and (7) encourage and assist in developing regional and local containment and prevention strategies and programs.

INTRODUCTION

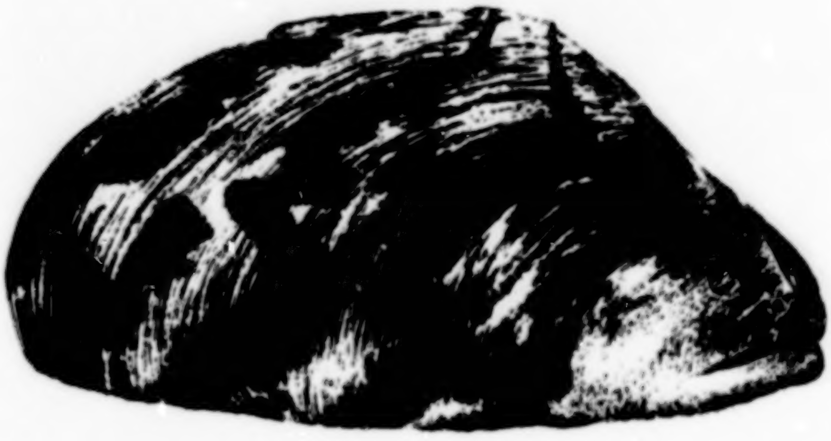


Figure 1. The exotic zebra mussel, *Dreissena polymorpha*, is an unwelcome invader of North American freshwater systems, where it has proliferated since its 1986 introduction.

The exotic zebra mussel, *Dreissena polymorpha* (Figure 1), has rapidly spread across the Eastern United States and Canada. This fouling organism has caused millions of dollars of damage to municipal and industrial water facilities, and this damage has generated much interest in control technology (Miller et al. 1992). However, little progress has been made in preventing the spread of the zebra mussel because the mussel has spread so quickly that prevention efforts have generally not been implemented before the mussel invaded. Thus, the major efforts to combat the zebra mussel in the Eastern United States have focused primarily on its control and eradication (Nalepa and Schloesser 1993). Until recently little has been done to address its containment and the prevention of its further spread.

Most experts believe that, in the absence of effective preventative measures, spread of the zebra mussel to every habitable region of North America is inevitable (Carlton 1993). The brief history of the zebra mussel invasion and spread in the United States, and its known dispersal elsewhere (Carlton 1993), suggests that it is only a matter of time before the zebra mussel spreads across the Western United States.

The Western United States has large arid and semiarid territories that may provide the first realistic opportunity to slow or stop the further spread of the zebra mussel. It is unknown how effective the zebra mussel will be in colonizing aquatic environments in arid regions, but there is little doubt that it will do well in some locations and environments. As an example, this species may thrive in the moist environment of the Pacific Northwest, where it could adversely affect aquatic systems that may already be stressed by anthropogenic development. Large

water resources projects in the West may be especially vulnerable to adverse affects associated with zebra mussel infestation in the East.

It is recognized that zebra mussels may eventually colonize western areas. However, if the present, rapid spread of the zebra mussel could be reduced for only a few years, it could save millions of dollars in potential damages to water management facilities. A delay in the spread of the zebra mussel also would allow for a more gradual conversion of vulnerable facilities to develop and install zebra mussel-resistant measures. It also could allow time for the development of processes and procedures for protecting sensitive species and their environments judged at risk, including threatened and endangered species populations, and to develop zebra mussel prevention and management measures for them.

The mechanism of, and potential impacts from zebra mussel infestation into the Western United States are unknown. Modes for its western dispersal may be different than those in the East. Therefore, actions necessary to prevent or at least slow the spread must first be identified before they can be implemented. These activities would, no doubt, be expensive and require an extensive commitment from many agencies and organizations. But the potential for environmental and economic losses dictates that attempts be made to stop, or at best reduce the spread of zebra mussels.

The U.S. Congress passed the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (PL 101-646) in an attempt to reduce the spread of a host of exotic species that were already established, and to further limit new introductions of nonindigenous species. Although much of the stimulus for the passage of this act was due to the invasion of the zebra mussel, efforts to date have done little to prevent the spread of this species into many waterways in North America and prospects for its eradication are low. In this context, the U.S. Congress, Office of Technology Assessment (1993) recently completed a comprehensive report on harmful nonindigenous species in the United States, and stated "...Federal and State policies designed to protect us from the worst species are not safeguarding our national interests in important areas." This Congressional report further indicated that harmful nonindigenous species are spreading because there is little or no Federal guidance or regulations, and State efforts to regulate importation, possession, introduction, and release of nonindigenous species are generally inadequate.

This report was initiated to develop a framework for future efforts to

reduce, and perhaps to prevent further westward spread of the exotic zebra mussel across the North American Continental Divide. However, during the course of this evaluation, it became evident that some western areas could remain free of zebra mussel contamination if certain management techniques were implemented. Because an uncontaminated buffer zone between the Continental Divide and the East was considered necessary to prevent further spread of the mussel, the area to be considered was expanded to include all uncontaminated areas east of the Continental Divide. Thus, three scenarios were judged as pertinent for reducing or preventing the western spread of the mussel, as follows: how the mussel might be prevented from crossing the Continental Divide; how zebra mussels might be excluded from areas immediately east of the divide; and whether the zebra mussel might be contained to areas that are presently contaminated.

The goal of this report is to determine the feasibility of reducing and preventing further western spread of the zebra mussel, and what role might the Service have in this endeavor. Objectives were: (1) to determine probable pathways and vectors that may be associated with the westward spread of the mussel, whether these pathways and vectors might be controlled, and how; (2) to evaluate strategies and tactics that might be used to prevent further western spread of the zebra mussel; (3) to determine what measures the Service, or others should take to monitor and control these pathways and vectors; (4) to evaluate the probable impact that may be associated with invasion of the zebra mussel into western ecosystems; and (5) to identify what actions, if any, should be taken by the Service in the near future.

The exotic zebra mussel, *Dreissena polymorpha*, is an unwelcome invader of North American freshwater systems. This species was discovered in Lake St. Clair in 1988, where it presumably was established from discharges of ship ballast water in 1986 (Miller et al. 1992; Leach 1993). The freshwater ballast, obtained in an European port, probably discharged veligers which thrived in food-rich Lakes Erie and St. Clair. The zebra mussel spread throughout the Laurentian Great Lakes in the United States and Canada, and into 11 States in the next 4 years (Figure 2). It has been detected in the Mississippi River above and below the mouth of the Missouri River, in the Arkansas River, and has probably found its way into the Missouri River (although undetected as yet). Zebra mussels are expected to spread in the Mississippi River, where their dispersal has been similar to that documented for the Great Lakes (Tucker et al. 1993).

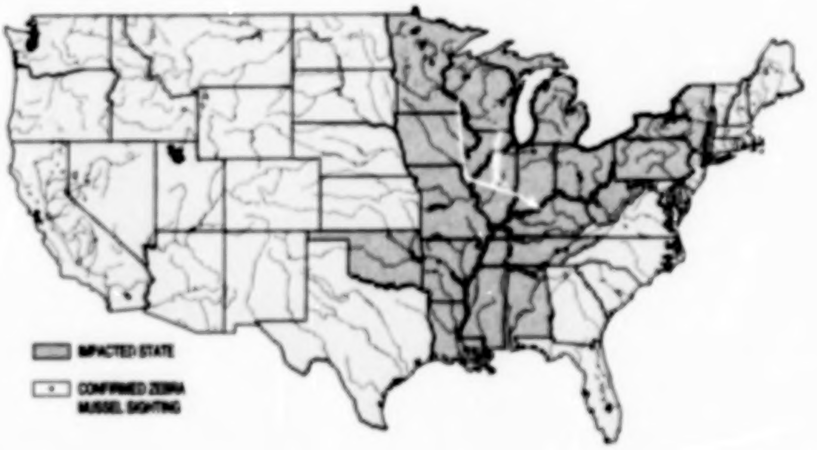
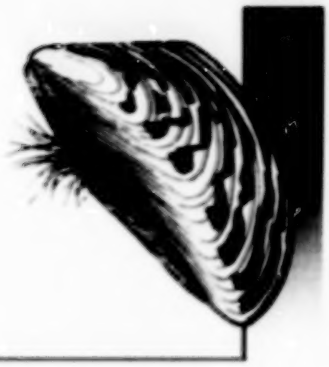


FIGURE 2. ZEBRA MUSSEL SIGHTINGS.

Native to the Caspian region of western Russia, the zebra mussel historically inhabited the Aral, Caspian, Azov, and Black seas. The species also was a common inhabitant of the mouths of large rivers that flow into these saline basins (Karnaukhov and Karnaukhov 1993). The zebra mussel began increasing its range in the 19th century by invading North European rivers that emptied into the Black Sea, presumably in response to canal building and increased eutrophication (Karanaukhov and Karanaukhov 1993). Europeans have experienced its continuing invasion through shipping canals for nearly 200 years (and more recently in association with hydroelectric projects). By about 1930, the mussel had spread throughout Europe and had reached Great Britain. Scientists have speculated (since about 1921) that zebra mussels might be transmitted to the United States by shipping (Nalepa and Schlosser 1993), but little was done to reduce the likelihood of such an invasion.



Once established, the zebra mussel is a prolific colonizer. Maturing within 12 to 18 months in favorable environments, it may spawn more than once a year, and production of over 1 million eggs per season is possible from one female (Miller et al. 1992). Fertilized eggs develop into free-swimming larvae (veligers) that can remain suspended in the water for a month. Larvae attach to hard surfaces and transform into the hard-shelled form (post-veligers). Up to 700,000 post veligers/m^2 have been reported to settle in raw water systems during a single spawning season (Miller et al. 1992; McMahon et al. 1993). In Lake St. Clair, the striped, yellowish-brown mussels grow nearly an inch in the first year, reach a size of 1.5 to 2 inches, and live about 3 years (Mackie 1993).

Young zebra mussels settle on various surfaces and firmly attach to them with threads secreted from a gland at the base of the muscular foot (Miller et al. 1992). They also can attach to each other, and thus form mussel clusters with population densities of 5,000 to 30,000 mussels/m^2 not being uncommon. High densities of 342,000 to 700,000 mussels/m^2 have been reported (Miller et al. 1992; Leach 1993), and at high densities zebra mussels can form dense mats of 12 inches thick or perhaps more. Because concrete structures, steel pipes, and other man-made items are good attachment substrate for the mussels, they have become a major problem for industrial and municipal water supply facilities. Severe problems to power plants have been caused by zebra mussel colonization inside pipes (Figure 3).

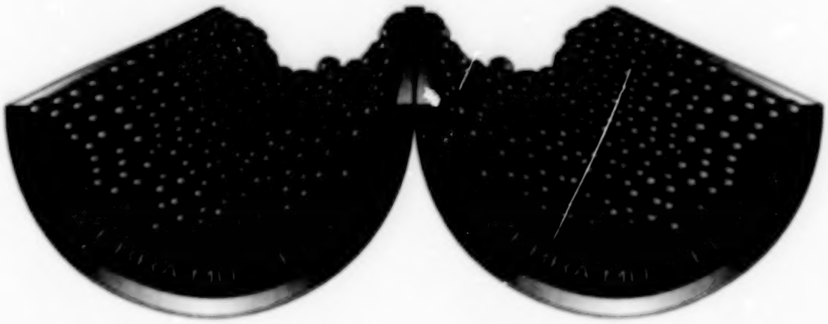


FIGURE 3. PIPE BLOCKED WITH ZEBRA MUSSELS.

After its introduction into Lake St. Clair, economic damages caused by the mussel in the Great Lakes was estimated at $5 billion (Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990). Infestations of zebra mussels ranging from 1,000/m^2 to 750,000/m^2 have been recorded from 10 power plants located from Lake Huron to Lake Erie (Kovalak et al. 1993). Costs to the power industry alone has been estimated at $3.1 billion over a 10 year period, which includes costs for plant shutdown, new design, and annual maintenance (U.S. Congress, Office of Technology Assessment 1993). Some power plants have expended costs of $250,000 per year

and more on control of zebra mussels (Miller et al. 1992).

The City of Monroe, Michigan, serves as an example of how municipalities can be adversely affected by the zebra mussel. The zebra mussel was first detected in the raw water system for the city in January 1989. By July 1989, the Lake Erie water intake for Monroe, a community of 24,000, was reduced 20% by the infestation of the mussel, and outages occurred from the winter of 1989 to the spring of 1990 (LePage 1993). The costs of controlling the zebra mussel at this facility was estimated at about $301,000 spent between January 1989 and January 1991, about $100,000 more for 1991 expenditures, and an extra burden of additional annual operating costs that will be required as long as the facility is infested with the zebra mussel. Control measures at the Monroe facility are dependent on heavy chlorination. If this facility is required to use other, more environmentally acceptable means for control of the mussel, such as ozone treatment in lieu of chlorination, additional costs could be $3 million for a new treatment plant (LePage 1993).

Due to its propensity to move from one location to the other, the zebra mussel has been called the "wandering mussel". In this respect, zebra mussels differ from other native freshwater bivalves in North America that do not have planktonic larvae. Zebra mussels colonies appear barnacle-like, but unlike barnacles, the zebra mussel can drop its attachment and undertake movements like other clams. If more desirable locations are found later, the mussel can regenerate threads and reattach. The juvenile mussels can break away from their attachments and generate new, buoyant threads that enable them to drift with the currents and find a new substrate. Adults are able to move to a new location with their muscular foot.

Zebra mussels can indirectly affect humans by attaching to various man-made and other substrates, but directly affect native mussels (unionids) and other animals (e.g., crayfish and turtles) by attaching to them. Mean densities of 6,777 zebra mussels attached per unionid have been reported in Lake Erie (Schloesser and Kovalak 1991). This can lead to eventual death of host mussels, and has resulted in the decimation of native mussels in Lake Erie (Stolzenburg 1992).

Zebra mussels feed by filtering plankton and other suspended matter from the water and depositing it in the form of feces and pseudofeces (Scholoessaer and Kovalax 1991; Griffiths 1993a; Tucker et al. 1993). An adult zebra mussel filters about 1 liter of water per day (Leach 1993), removing virtually all of the plankton from the water in the process. Zebra mussel feeding is causing physical, chemical, and biological changes in

aquatic ecosystems of the Great Lakes (Griffiths 1993a). Water clarity in some areas of Western Lake Erie increased as much as 85% during May through November, 1988 and 1989, and Chlorophyll A declined 54% during this same period (Leach 1993). Changes in the benthic fauna of the Great Lakes have occurred, including the loss of native mussels (Schloesser and Kovalak 1991; Griffiths 1993a; Stolzenburg 1992), and standing crops of some fishes, including walleye have declined (Griffiths 1993b).

PARAMETER	REQUIRED LEVEL
pH	≥7.0
Salinity	<2000 mg/L
Calcium	≥25 mg/L
Temperature	Cold Zone with Monthly Maximum = 12°-18° C requires ≥ 4 Months At ≥12°C Mild Temperature with Monthly Maximum = 20°-28° C requires ≥ 3 Months At ≥15°C Warm Zone with Monthly Maximum = 28° C requires Annual Mean ≥15°C
Turbidity	80 NTU
Eutrophy	Total Phosphorus <0.25 mg/L or Total Nitrogen <4.0 mg/L

Table 1. Limnological parameters required for Zebra mussels in North America (after McNabb 1993)

If left unchecked, the zebra mussel could become common throughout the temperate zone of North America within the next 5 to 10 years. This single species poses a multibillion dollar threat to industry, governments, and individuals due to its impact on industrial and public water supplies of the Nation, as well as shipping, boating, fishing, and other recreational activities. Its affect on natural systems is more difficult to quantify, but the damage and cost associated with endangerment and loss of species, and the disruption of natural systems could be even greater. Although some waters may not be suitable for zebra mussel proliferation, conditions must be extreme to exclude them (highly eutrophic or oligotrophic, extremely warm, etc.; Table 1).

The rapid movement of the zebra mussel from the Great Lakes into connecting waterways and the Mississippi River has left little time to set up programs to evaluate the risks that it poses to natural systems. Although much general information has been obtained about the impacts of zebra mussel on fresh water environments, the potential effects on sensitive western ecosystems are unknown.

STRATEGY

A review of existing information about the spread of the zebra mussel indicated that most of the documented spread across Europe occurred during the industrial revolution, and primarily through interconnecting waterways. No information was available about the spread of the mussel in arid areas, and not enough information was available to evaluate the role of overland pathways in spreading zebra mussels. The one thing that did become clear was the rapid rate at which the animal can spread in the absence of preventative measures. Because it appeared that time was of the essence in dealing with this species, efforts were focused on the use of existing laws, regulations, permits, partnerships, and other potential methods presently applicable for restricting the spread of the zebra mussel.

In order to prevent the spread of the mussel across the Continental Divide, it was presumed that much could be gained by slowing the western spread of the mussel as quickly as possible before the divide was reached, i.e., by containment of the animal to waters east of the divide. One of the first steps in developing this plan was to define the area that had the greatest potential for invasion (i.e., the "target" area) and areas from which the zebra mussel might spread into the target area (i.e., "contaminated" area). Existing pathways and vectors that might be involved in further westward expansion of the zebra mussel, and possible controls that might be exercised in an expeditious manner were determined and evaluated. This evaluation used standard tactics similar to those used to combat an epizootic, or epidemic outbreak of a contagious disease. Thus, pathways through which the organisms might be spread, vectors that might be the "contagious" agent, and methods of containing, restricting, or otherwise controlling the vector

were identified. Specific control techniques used for direct zebra mussel eradication were not considered.

Early detection of zebra mussels in an area and monitoring programs to determine their densities have been used to develop control options for various facilities in the Eastern United States (Kovalak et al. 1993). Therefore, detection and monitoring programs were evaluated for potential utility in reducing the western spread of the mussel. Experience elsewhere has shown that first detection of settled mussels in an area, even though it was being monitored, almost always came from other, unplanned sources from the public sector (Kraft 1993). Because intensive and costly monitoring programs for the larva provides little preinvasion warning for the settled mussels (Kraft 1993), it appears that an effective information and education program would be extremely useful in detecting the presence of zebra mussels in the West. Once detected, monitoring may be helpful in determining alternative control options at various facilities.

VECTORS

VECTOR, A TERM WIDELY USED BY HEALTH ORGANIZATIONS, IS USED HERE TO IDENTIFY THE ACTIVE OR PASSIVE MEANS BY WHICH THE ZEBRA MUSSEL IS MOVED OR CARRIED FROM ONE LOCATION TO ANOTHER.

Just as the mosquito is a vector or carrier of many diseases, seagoing vessels, contaminated bait buckets, and others are examples of vectors or carriers of the zebra mussel. In most cases, the spread of the zebra mussel through a pathway requires a separate vector. The most obvious exception is the down-stream drift of the organism in a stream. (It could be reasoned, however, that the stream and water flow constitute the pathway and vector).

There are many vectors that are responsible, or potentially responsible, for the spread of zebra mussel in the environment. Carriers can be intentional or unintentional. For the purposes of this document we will deal mainly with unintentional spread by commercial and recreational vessels, commercial fishing nets and equipment, sport fishing boats and equipment, transfer of water by trucks, pumping in pipes and canals, airplanes, and amphibious equipment. However it is also possible that some intentional introduction might occur. As a case in point, aquarium dealers in the Denver metropolitan area have sold another exotic mollusc, the Asiatic clam (*Corbicula fluminea*) to hobbyists, and its invasion of Cherry Creek Reservoir there might be due to escapement, or release from aquaria (Dr. Cal McNabb, U.S. Bureau of Reclamation, Personal Communication, 1993). The zebra mussel, because of its brighter colors and its ability to attach to the sides of aquaria, may enter into the aquarium trade.

Transport of adult and larval zebra mussels by boat and trailer is considered a major problem for the West. Many people trailer boats and motors across the country for fishing tournaments, recreational fishing, and pleasure boating. Adult zebra mussels may be attached to hulls, motors, or in motor compartments. Larvae may occur in live wells, bilge water, or in

the internal parts of motors or trailers. Transfer of a few adults or larvae can, in time, result in the establishment of a new population of zebra mussels if environmental conditions are suitable.

The transfer of water could result in the spread of zebra mussels due to the pelagic egg and a free-living larval stage of this species (Note: North American unionids have neither). Therefore, any water taken from a contaminated river or lake during the zebra mussel breeding season (which may last from June to October; Garton and Haag 1993) could potentially contain the organism. Equipment used to move water from a contaminated drainage to another uncontaminated drainage could be called a vector in this context.

Vectors for spreading zebra mussel veligers, include the use of tank trucks and equipment by bait dealers, State and Federal fish distributors, the aquaculture industry, and the aquarium trade. Zebra mussels can also be spread in irrigation water, introduced with hatchery bait or aquarium fish, or attached to, or on, various items such as plastic bags, boxes, and packing that are used by fisherman, the aquarium trade, and by the aquaculture industry.

PATHWAYS

Further western invasion of zebra mussels would occur as a carrier (vector) transmits the species by the use of various pathways. Land pathways would require the services of a vector, but water pathways may (upstream transport) or may not (downstream transport) require a vector (Figure 4).

There are two geographic routes of importance for further western spread of zebra mussels in the United States: one from the eastern United States and one from Canada. Except for veliger transport from Canadian Rivers, this spread would require a vector along land and water routes (Figure 5) as documented by Carlton (1993) who reported zebra mussels transport by 3 natural and 20 human-related mechanisms (Table 2). The rapid spread of zebra mussels experienced in North

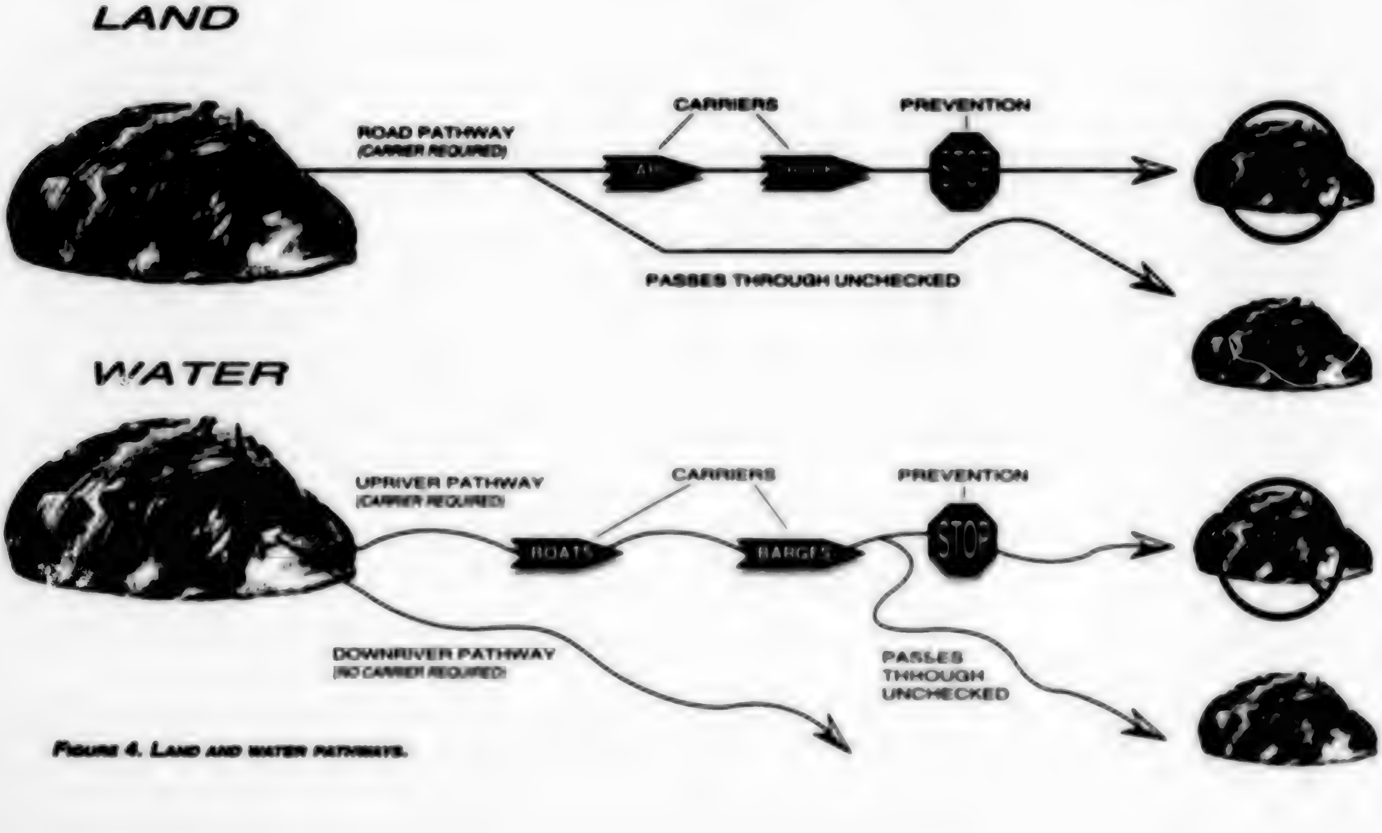


FIGURE 4. LAND AND WATER PATHWAYS.

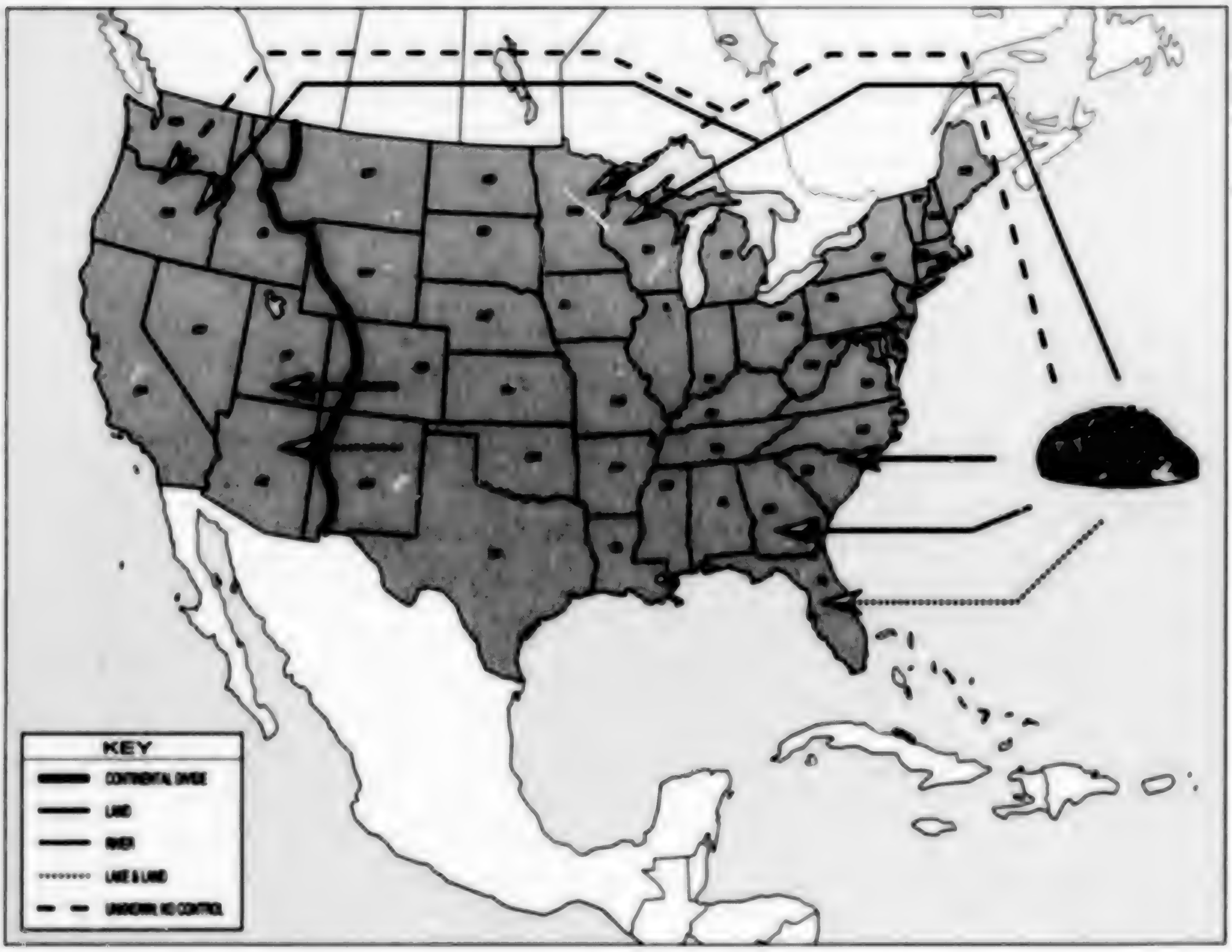


Figure 5. Pathways for zebra mussels.

America has been through shipping canals and waterways, and the primary means of its transport in North America appears to have been by shipping. This mode of transmission has presumably been efficient, and adult zebra mussels attached to the hulls of barges and other vessels and boats might be expected to seed several harbors over one reproductive year. Also, new areas may be occupied when attached adults are rubbed off, or if they voluntarily detach.

The U.S. Army Corps of Engineers has studied the transport of zebra mussels in the inland waterways and determined that barges are very likely responsible for the rapid spread of the mussels throughout the inland system. Of note is the case of a single barge that travelled 14,000 miles through the inland waterway system between May 1991 to May 1992. On May 11, 1992, zebra mussels were observed on the barge, occurring: "... in clusters every 2 to 3 feet along the bottom edge of the rub rail ... 10 to 50 zebra mussels were found in each cluster." (U.S. Army Corps of Engineers 1993). The size of the mussels suggested that they attached to the barge in 1991. These mussels probably spread during reproductive periods and perhaps anytime when the barge scraped along locks and other facilities, dislodging the adult mussels.

MECHANISM	UPSTREAM		DOWNSTREAM	
1. Natural	**YES**	**NO**	**YES**	**NO**
a. currents		■	■	
b. birds	■		■	
c. other animals	■		■	
2. Human	**YES**	**NO**	**YES**	**NO**
d. canals(may include pumps)	■		■	
e. ballast water	■		■	
f. vessels	■		■	
g. buoys	■		■	
h. marina/fishing equipment	■		■	
i. fish stocking, bait buckets	■		■	
j. trucking water	■		■	
k. intentional movements	■		■	
l. aquaria releases	■		■	
m. amphibious airplanes	■		■	
n. recreational equipment	■		■	
o. litter, garbage	■		■	
p. scientific research	■		■	

TABLE 2. DISPERSAL MECHANISMS FOR ZEBRA MUSSELS (AFTER CARLTON, 1993). (NOTE: SOME CATEGORIES HAVE BEEN COMBINED).

The downstream spread of zebra mussels in the Mississippi system and its lateral transportation due to commercial water traffic will not be a factor in the further western dispersion of zebra mussels in the United States. (Note: There are some streams that enter the United States from contaminated areas in Canada, and this problem will be discussed later). Thus, downstream colonization by zebra mussel veligers, a major problem in the Eastern United States, is not viewed as great a problem for direct western

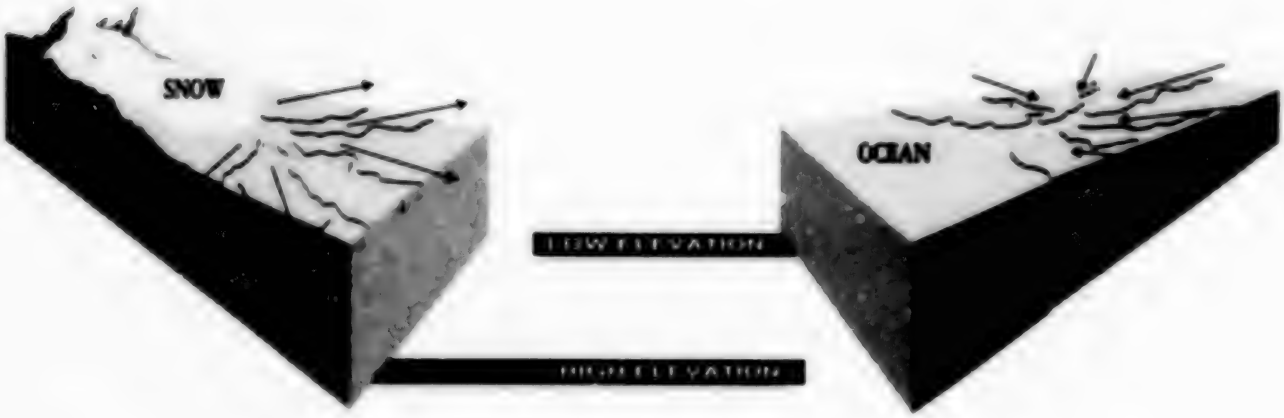


Figure 6. Hydrology at different elevations.

expansion of the species to the Continental Divide. Thus, it is assumed that further western expansion of this species will require the services of a vector.

However, if zebra mussels are introduced into headwaters west of the Continental Divide, they could be rapidly distributed by downstream drift of larva. However this spread would occur differently than has been the rule in the Eastern United States. In mountainous portions of the arid West, water is collected in headwater reservoirs or withdrawn from receiving waters, transported via canals, and pumped to agricultural and municipal areas for consumptive and nonconsumptive uses. In contrast, at lower elevations and wetter climates, effort is spent to drain excess surface water that occurs from local heavy rainfall, and transport it to larger downstream receiving waters and to the Oceans (Figure 6). Thus, if zebra mussel are introduced into higher elevations of the Western United States, larva could be widely distributed in a very short period of time.

LAND PATHWAYS AND VECTORS

The land pathway includes highways, roads, trails, and paths that could be used to transport zebra mussels. The primary means of long distance overland dispersal of zebra mussels has been by transport on small boats on trailers (Griffiths et al. 1991). It is presumed that transport of zebra mussel by land pathways would principally occur by transport of boats that have zebra mussels attached to them, or by transferring contaminated equipment, such as nets and live wells, from one body of water to another. Adult zebra mussels may be entangled in nets and equipement, or the free-living larva may also be present in water entrapped in the boat motor, live well, or any other moist area. Zebra mussels that are attached to boat hulls and other exposed areas can be killed in hot weather (e.g., if exposed for 2 days at 35°C; Jenner and Janssen-Mommen 1992). However, recent studies have shown that even at about 0% relative humidity, it takes an exposure duration of at least 3 days (McMahon et al. 1993) to kill adult zebra mussels at 25°C, and more than 10 days is required if the temperature is 15°C or less. Thus, it is likely that adult zebra mussels could be inadvertently transported to the West by boaters, especially during cool weather.

The zebra mussel has been found as far west as Wisconsin, Iowa, Missouri, Arkansas, and Louisiana, and it was recently found in the Arkansas River in Oklahoma (Figure 2). Although yet undetected, it probably invaded the Missouri River system via barge traffic to the head of navigation at Sioux City, Iowa, and it may soon be found in the waters of Nebraska, South Dakota, and North Dakota. It is also presumed that there may be further invasion into Oklahoma, Texas, Kansas, Colorado, and New Mexico from the Arkansas River. Because there has been widespread dispersal and transport of zebra mussels in Canadian waters, the

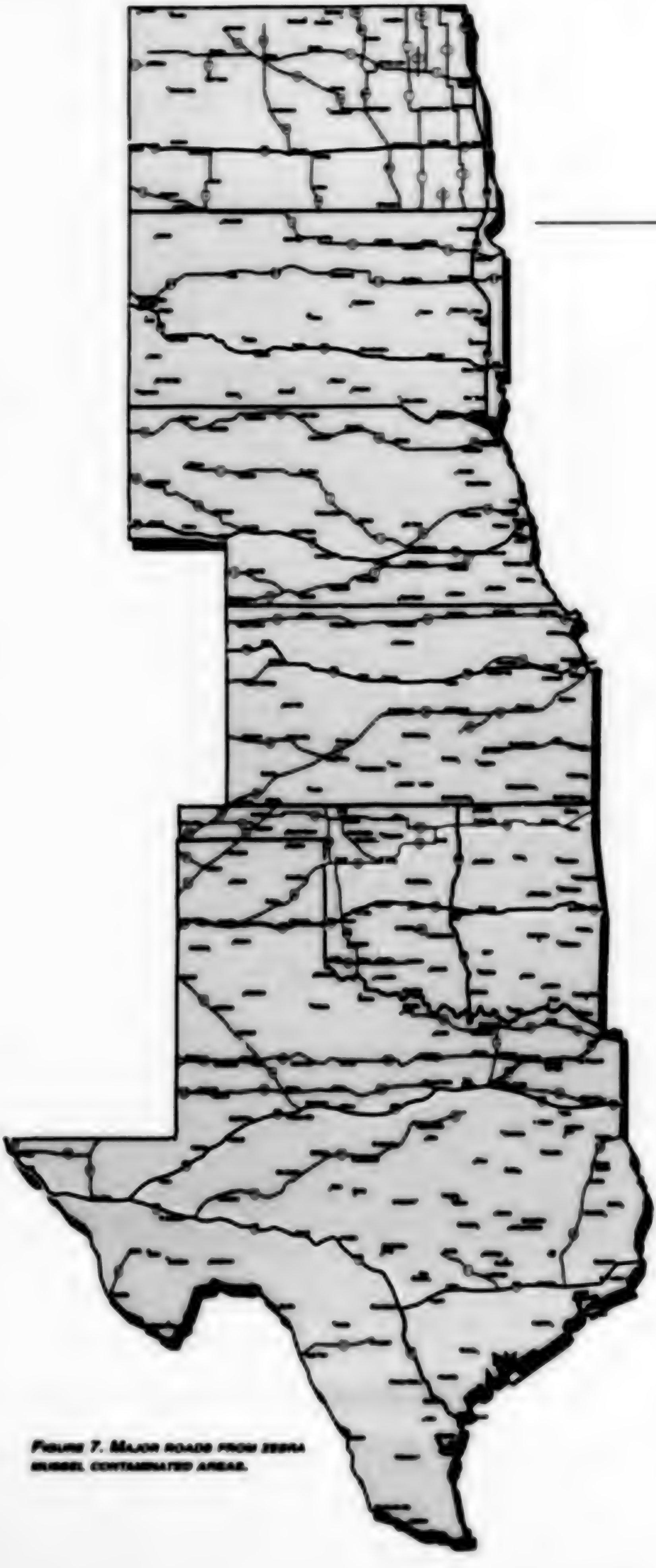


Figure 7. Major roads from zebra mussel contaminated areas.

possible southerly transport of zebra mussels from Canada into North Dakota, Montana, Idaho and Washington must also be considered.

In evaluating potential land routes westward from Wisconsin, Iowa, and Missouri, and southward from Canada, major roads likely to be traveled by people trailering boats to uninfected areas were identified (Figure 7). This potential avenue for introduction represents the first opportunity to stop the spread of the zebra mussel. In order to prevent the spread, check stations with inspectors and disinfection equipment could be set up on each of these routes.

Land transport of the zebra mussel west of the North American Continental Divide from the east can occur only via a restricted number of roads (Table 3), and in some States there are only a few. Figure 8 presents the Federal and State highways across the Continental

Divide for each State. These routes represent the last opportunity to prevent introduction, and each route should have check stations for all vehicles pulling boats and trailers.

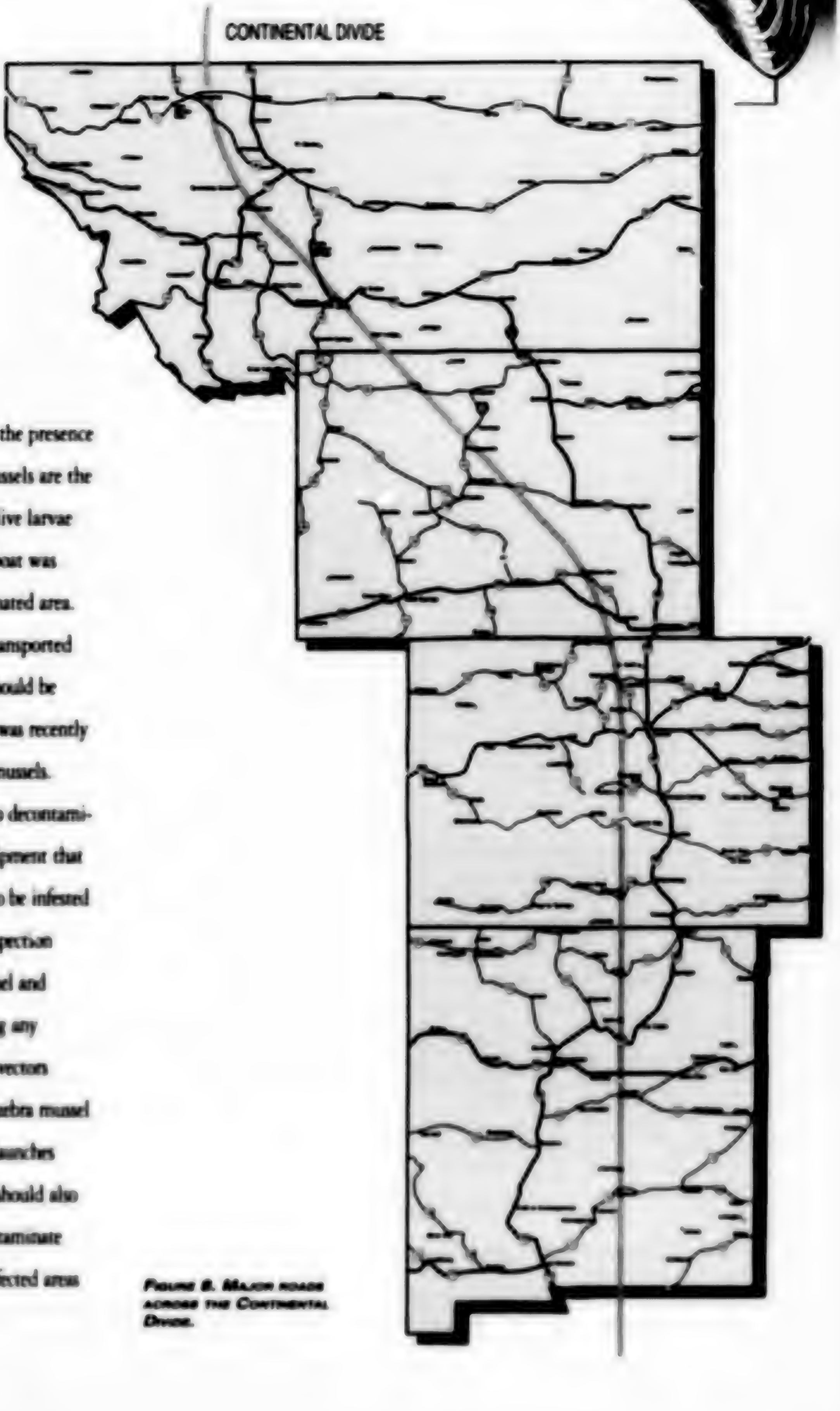
States and other agencies have tried to educate the traveling public about the dangers inherent in spreading zebra mussels and how they might be inadvertently transported. Because of the possibility of transporting the mussel via land pathways, several States have developed pamphlets and are using other public relations tools in an attempt to reduce its spread. Public information and education could be an important part of the prevention program for reducing the spread of the zebra mussel.

Even with an effective public education program, there may be uninformed, negligent, and perhaps well-meaning people who intentionally spread zebra mussels. Potential actions of these individuals must also be considered. Carlton (1993) reported several historic accounts in Europe, where people intentionally transplanted zebra mussels into new water systems for various purposes, such as increasing the "...diversity of nature". We believe that this could also happen in the Western United States, where reasons for intentionally transplanting zebra mussels could be to improve water quality in ponds, to provide food for waterfowl or mollusc-eating fish (*i.e.*, freshwater drum, sunfish, etc.), and possibly for culture purposes (for aquaria, fish bait, etc.).

If the potential spread of zebra mussels is to be controlled, specific measures need to be established along the highways and roads between the infected and uninfected areas. Watercraft and trailers in transit along western routes should be monitored if

STATE	FEDERAL HIGHWAYS	STATE HIGHWAYS
MONTANA	I-15, I-90, 2, 89, 192, 20,26, 287	200, 43, 324, 48, 2, 279
WYOMING	I-80, 20, 89, 287, 191, 26, 28, 30	28, 789
COLORADO	I-70, 40, 34, 36 24, 50, 160	9, 91, 82, 114, 149
NEW MEXICO	I-40, I-10, 64, 84, 84, 60, 180, 70	112, 96, 44, 163, 38, 9, 81, 197, 509, 371 53, 603, 12, 159, 146

TABLE 3. MAJOR LAND ROUTES ACROSS THE CONTINENTAL DIVIDE IN THE UNITED STATES.



possible, and inspected for the presence of zebra mussels. Adult mussels are the easiest to detect; however, live larvae might also be present if a boat was recently used in a contaminated area. Any boat or vessel being transported from a contaminated area should be inspected to determine if it was recently used and/or contains zebra mussels. Means should be available to decontaminate boats, motors, and equipment that might be suspect or found to be infested with zebra mussels, thus inspection stations should have personnel and facilities for decontaminating any suspect equipment or other vectors capable of transmitting the zebra mussel or larva. Marinas and boat launches close to contaminated areas should also have the capability to decontaminate water craft entering from infected areas of the country.

Figure 8. Major roads across the Continental Divide.

There are many lakes, reservoirs, canals and other waters in the Western United States that are intensively managed for recreation, flood control, power, and other uses. Examples of these areas are State and National Parks, National Recreation Areas, and waters managed or controlled by the Bureau of Reclamation, Corps of Engineers, or other management agencies. In these cases, the launching of boats, fishing, and other human use are under supervision. As a result, these areas are already equipped to exclude zebra mussels, and in many instances, zebra mussel exclusion could be relatively inexpensive.

In addition to transport on boats or other marine equipment, another major mode of transmission across land may occur by transport of contaminated water. Many western areas permit the pumping of water from a stream or other body of water into a truck to be used in road construction, well drilling, farm irrigation or for other purposes, including emergency use of water to fight fires. Such exchange of water could conceivably spread contaminated water between one river system and another. Another item of major concern is the transfer of fish or other aquatic animals in water from contaminated areas to uncontaminated areas. Control of this mode of zebra mussel transmission must be examined and potential quarantine programs evaluated.

Natural vectors that might transmit zebra mussels overland include turtles, water snakes, and other riparian or amphibious animals. This mode of transmission may be significant for short distances, but it is not anticipated to be a major factor in western expansion of the zebra mussel range.

There are many available means whereby the zebra mussel might be transported via land pathways. Many of these may be important for local transport. However, the primary method of zebra mussel transport across the Continental Divide is anticipated to be by boats, motors, and/or trailers. Because there are so few routes that are available for transporting boats across the Continental Divide, it seems feasible that some type of regulatory mechanism would be effective in stopping them. Although inspection stations are not generally located on the passes across the Continental Divide (due to unfavorable weather conditions), cautionary or warning signs placed at strategic locations on roads leading over the divide might be effective in reducing the spread of zebra mussels.

Some states already have statutes forbidding the transport of zebra mussels (for example Minnesota). Other States that are especially vulnerable to economic damage are considering the passage of similar laws. In California, the State Department of Water

Resources has been actively involved in zebra mussel exclusion and risk assessment, and the State Department of Agriculture has agreed to begin an exclusion program for zebra mussels at its inspection stations (D.F. Peterson, California Department of Water Resources, Written Communication, 1993). Prevention efforts must involve working with States to leverage existing laws or pass new ones to prevent the spread of zebra mussels.

WATER PATHWAYS AND VECTORS

Water pathways have probably been the most common means of spreading the zebra mussel in the United States. The mussels are spread downstream as the veligers drift with the current. Once suitable habitats are reached, they attach to solid substrate such as rock, piers, or boats. In upstream invasions, the veligers must be aided by a vector, which may include boats and barges, or other carriers by which the mussel veliger can undergo passive transport. In contrast to land pathways, which are most likely to be in straight lines, water pathways are not. As indicated in Figure 4, only two major types of water pathways exist: direct conveyance of zebra mussels in lakes and rivers (downstream travel) and indirect transport by vessel.

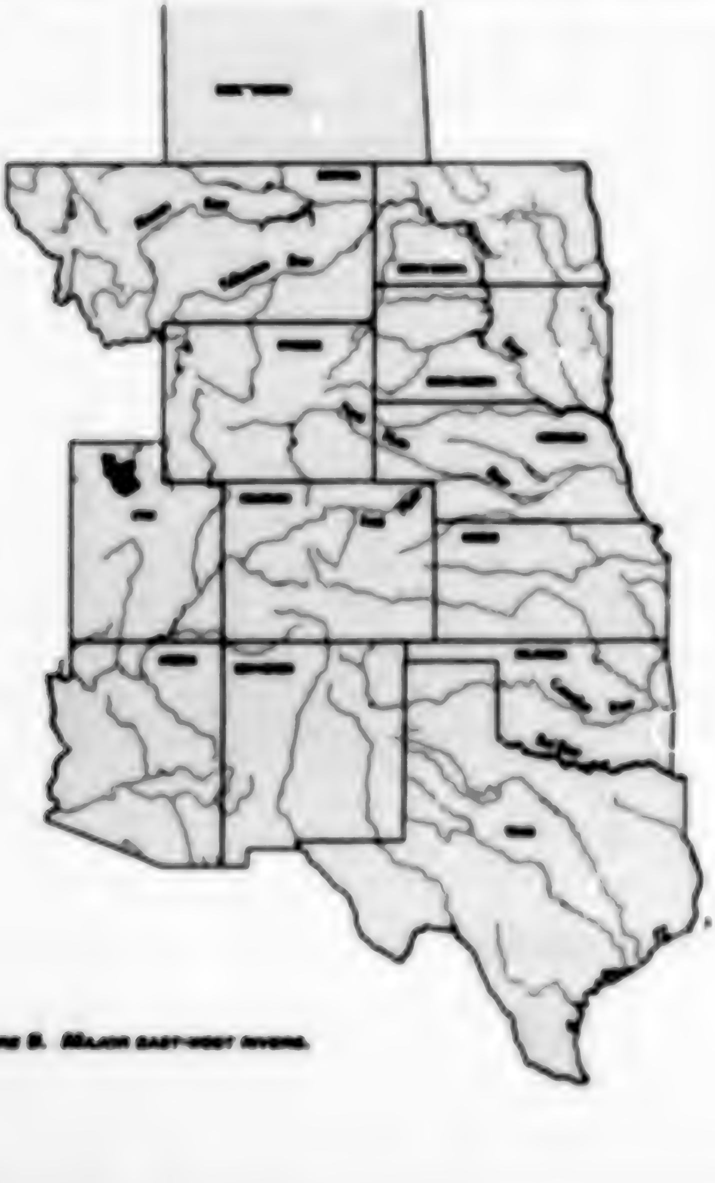


Figure 8. Major east-west rivers.

Information on major river systems in Europe which became infected with the nonindigenous mussel has shown that the mussel can be transported great distances both upriver and downriver within a short span of years. Modes of its upstream transport are generally not well understood, but Carlton (1993) suggested that the zebra mussel may be carried and transmitted by a host of natural and man-influenced means. All major rivers and waterways entering and connecting the western United States and eastern infested areas should be considered potential pathways (Figure 3). Major waterways are identified in Figure 9.

Waterways flowing between the infected and uninfected areas of the West should be monitored to determine if, and when zebra mussels are present. Once zebra mussels are detected, barriers or inspection stations could be established and water craft traveling in these routes could be restricted, or checked to prevent upstream movement of the mussel. Decontamination stations could be located at boat access sites to remove or destroy mussels before watercraft are launched into uninfected waters.

In addition to natural streams, many agricultural, municipal, and private diversion canals exist in the West. These include thousands of miles canals associated with projects constructed by the Bureau of Reclamation and other water developers. If zebra mussels enter these canals, they could rapidly proliferate throughout areas of suitable habitat in the West.

In addition to watercraft, other potential water vectors may include aquatic animals such as crayfish, fish, birds, and climatic factors such as water spouts and tornadoes. Because of topography, stream gradient, and dams and diversions, these vectors are not considered of major importance in the westward expansion of the zebra mussel.

mainly with unintentional spread by commercial and recreational vessels, commercial fishing nets and equipment, sport fishing boats and equipment, transfer of water by trucks, pumping in pipes and canals, airplanes, and amphibious equipment. However

Many people trailer boats and motors across the country for fishing tournaments, recreational fishing, and pleasure boating. Adult zebra mussels may be attached to hulls, motors, or in motor compartments. Larvae may occur in live wells, bilge water, or in

AIR PATHWAYS AND VECTORS

The third general pathway by which the zebra mussel may be spread is by air, including air traffic and shipments of contaminated materials. This may occur over long distance (i.e., across the continent or around the world), or from one small, contaminated lake to an uncontaminated lake just a few miles away (e.g., by float plane). Air shipments of tropical fish, aquatic plants, or some other product, may intentionally or unintentionally contain zebra mussel eggs, larva, or adults. Areas with significant amphibious aircraft traffic should be evaluated to determined if preventative measures should be implemented.

Potential natural vectors for the air pathway are ducks and other aquatic birds. It has been speculated that larva may attach to birds' feet or that birds may pick up zebra mussel laden sticks or other debris and carry them upstream or between drainages. The significance of this vector is unclear with respect to long range expansion of zebra mussels.

As discussed with the other identified pathways, public education, public support and inspection stations have the greatest potential for preventing spread via this pathway.

CONTAINMENT AND PREVENTION STRATEGIES

Once zebra mussels occur in a river system, there are no known methods of total eradication. It is believed that, as in case of the ruffe (*Gymnocephalus cernuus*; Busiahn 1993), the zebra mussel will spread regardless of control efforts. If true, the spread of the zebra mussel will only be curtailed through prevention efforts, not stopped. Effective prevention is a combination of containment (zebra mussels restricted to a certain area), and prevention (zebra mussels not entering a new area). Both measures must be instituted to prevent the further spread of zebra mussels into the western United States. The use of buffer zones can be an effective way to implement the concepts involved with containment and prevention.

A three-tiered approach appears to be appropriate for preventing further spread of the zebra mussels into the West. This approach offers three levels of implementation, from the highest risk for initial infestation to the lowest.

By this approach, actions can be prioritized and maximized for better efficiency. These three tiers involve setting up geographic boundaries as follows (Figure 10):

1st level of effort (P1)—Eastern border of ND, SD, NE, KS, and OK. This is the edge of the area presently contaminated with zebra mussel and efforts needed there would require implementation of containment measures.

2nd level of effort (P2)—Eastern border of CO, MT, WY, NM, and TX. This uncontaminated area is the western edge of the first buffer zone.

3rd level of effort (P3)—Canadian-U.S. border. This is also on the edge of a potentially contaminated area, and would involve an international containment boundary.

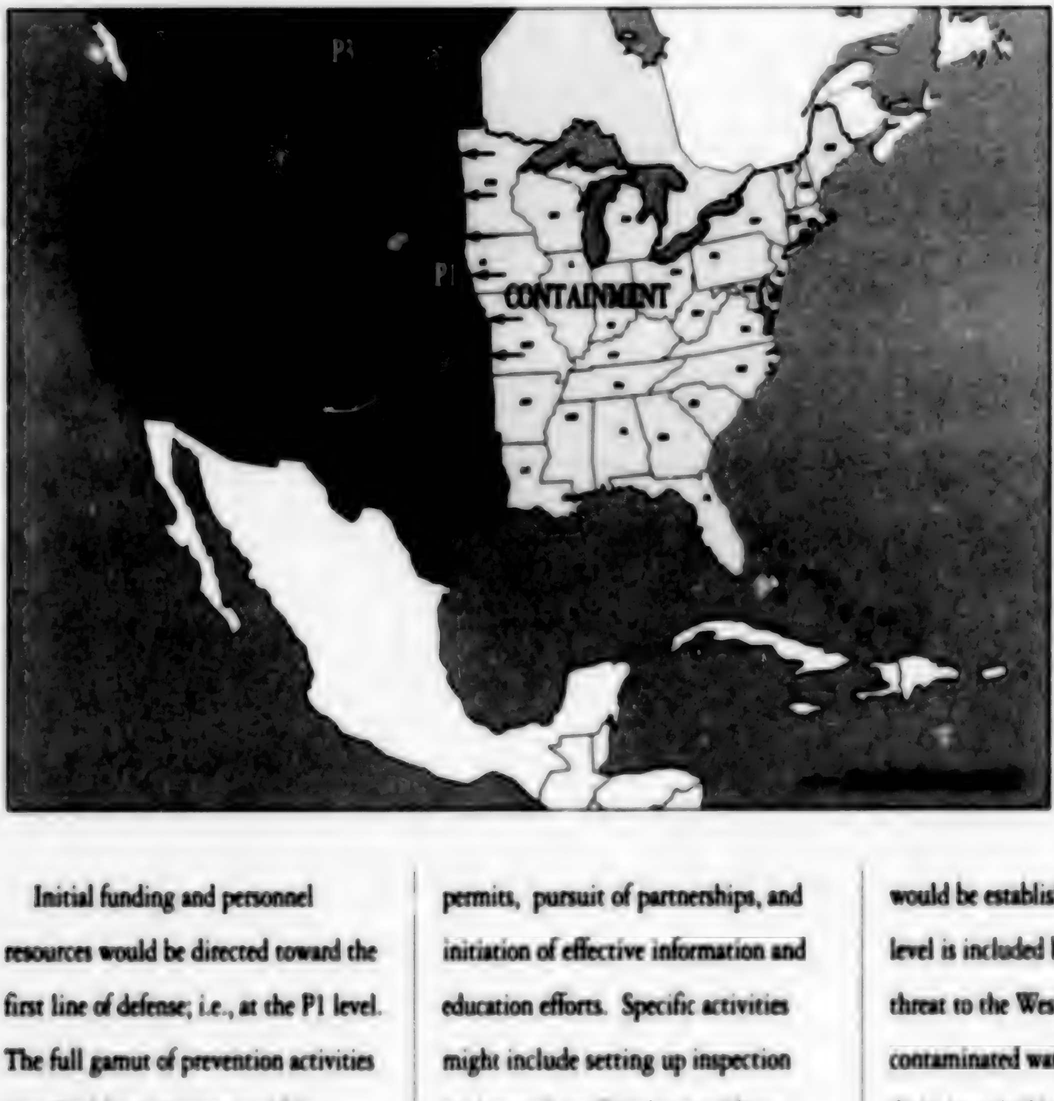


Figure 10. Containment of zebra mussels and prevention zones.

Initial funding and personnel resources would be directed toward the first line of defense; i.e., at the P1 level. The full gamut of prevention activities described for pathways would be implemented to contain the mussel east of the P1 states, and to reduce their spread through the P1 area. This would include evaluation and potential utilization of laws, regulations and permits, pursuit of partnerships, and initiation of effective information and education efforts. Specific activities might include setting up inspection stations and roadblocks, providing decontamination areas; and starting school education programs. The P2 level would be considered a worse-case scenario, or a failure of the P1 measures. Initially, a public awareness program would be established in P2. The P3 level is included because the last real threat to the West comes from contaminated waters in Canada that drain into the United States. The P3 area is the only location in which the Lacy Act might provide effective prevention measures.

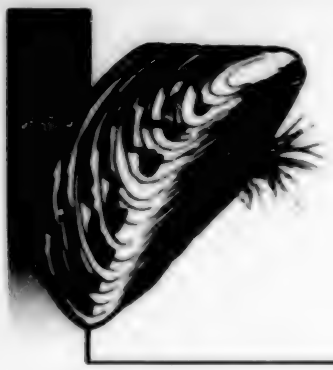
INFORMATION AND EDUCATION

There must be a commitment by responsible agencies in infested areas to prevent the transport of zebra mussels out of those areas and into noninfested areas. Information and Education programs (I & E) are essential for containment. Many U.S. and Canadian agencies and private organizations have developed programs to inform the public of the impacts associated with the invasion of zebra mussels. It is important for the people to know that efforts must be made to contain this animal to areas presently infected, and to make every effort to prevent further local spread into smaller uncontaminated bodies of water. This will serve two purposes: 1) to localize the infestation in an area, and 2) to contain in an area, thus preventing spread to noninfected areas. Present I & E programs must be utilized to the maximum extent possible (e.g., Sea Grant). Although the well-developed programs of the Eastern United States do not presently exist in the Western United States, they can be used as prototypes for developing them.

The main emphasis of I & E programs should be to address private individuals and inform them about ways they can prevent further spread of the mussel. As previously stated, educated public observers are likely to provide the first reports of zebra mussels (Kraft 1993). Because the West is so large and sparsely populated, public cooperation and participation is necessary if the objectives of this document are to be achieved.

Information and education efforts must be shared with as many other agencies and private groups as possible. Recommended objectives of the I & E effort are to:

1) convince State and Federal agencies that the zebra mussel can cause adverse impacts to the West, encourage these agencies to make preventing the western spread of the zebra mussel and other



nonindigenous species a high priority, and encourage them to abandon their current "wait and see" philosophy in favor of a proactive one while there is still time.

(2) develop an awareness of the problem among the personnel of the U. S. Fish and Wildlife Service, and develop MOU's or other agreements with closely-allied agencies such as the Bureau of Reclamation, Corps of Engineers, and State fish and game agencies to prevent the spread of nonindigenous species.

2) Educate and inform the public so they will understand how they can assist in slowing or stopping the spread of the zebra mussel, especially through early detection and monitoring.

3) Develop support from the public and other agencies in order to pursue the main objective of stopping the westward spread of the zebra mussel.

To be effective, the Service should take a lead role to prevent further spread of the zebra mussel and other nonindigenous species. This can be facilitated internally by establishing a high priority by the Director and developing a National policy and Directive by the Secretary of the Interior. It is also necessary that proper laws be enacted and existing laws such as the Aquatic Nuisance Act be fully funded. In addition, regulations pursuant to provisions of this act must be promulgated and enforced to reduce further spread of aquatic nuisance species.

Externally, the Service must coordinate with other federal agencies, state agencies, and leaders in the general public to establish Information and Education programs in the West. Many organizations have initiated public education programs in the East regarding the zebra mussel, and coordination with these entities is essential to minimize duplication of efforts and maximum use of our limited resources. The *St. Croix River Zebra Mussel Plan (1993 Interim Program)* (Klukas and Burke 1993) is a well developed plan that lists many existing zebra mussel programs. In that program and others, efforts range from producing brochures and videotapes to conducting sophisticated programs. In many eastern areas, Sea Grant offices have received funding for information programs, and have produced and distributed newsletters, brochures, and other information. Sea Grant programs usually target the specific coastal state in which they are located. Most of the zebra mussel programs have not been highly visible in the West.

As information programs develop to inform and motivate the public about

zebra mussel threats to the West, the media could be effectively utilized by having specialists involved to encourage development of television productions, newspaper releases, radio spots, magazine articles, and production of brochures for chambers of commerce, schools, parks, refuges, and hatcheries. Television, videos, and radio news releases may be produced at no charge if done through the public broadcast stations (PBS) as public service announcements. It will be important to develop sponsors and present information on television programs which deal with hunting, fishing, and nature such as National Geographic Explorer, Fishing the West, and Nature.

An effective I & E program also would include convincing editors and free-lance writers that they can perform a service to the public by educating them about zebra mussels and their threats. Specific articles should be prepared to target different audiences. This could include publications with national distribution such as *National Geographic* and *Life*, other periodicals with a more limited distribution geographically, or ones that target special interest groups such as State game & fish magazines, scientific journals, and newspapers.

It will require a great deal of work to prepare news releases, furnish articles to the publishers and broadcasting stations, and to contact editors of outdoor newspaper columns. Existing brochures could be utilized where applicable, but new ones, that discuss preventing the spread of the mussel rather than its control, should be developed. It will be necessary to be innovative in the distribution of the brochures in order to get thorough and effective coverage.

REGULATIONS, LAWS, AND PERMITS

It will be necessary to utilize Federal and State regulations, laws, and permits to contain and prevent further spread of the zebra mussel. However, it has been stated that present Federal and State regulations do not adequately protect the environment from the introduction of exotic species, and that the roles of various Federal and State agencies should be redefined (Kurdila 1988; U.S. Congress, Office of Technology Assessment 1993). Although the use of statutes, regulations and permits will need further investigation and evaluation with respect to zebra mussel control that is beyond the scope of this report, some existing measures are pertinent and applicable:

Federal statutes- The zebra mussel was designated a species of injurious wildlife on April 27, 1992 (57 FR 16876). The mussel, therefore came under the authority of the Lacy Act by this designation, and it was added to the list of injurious fish, mollusks, and crustaceans (50 CFR 16.13). As part of this action, the Service prohibits importation of live zebra mussels or viable eggs into the United States or any territory or possession of the United States. Thus, the Lacy Act prohibits transport of this species into the United States from Canada. The U.S., and perhaps Canadian border agents, should be required to inspect all boats, water carriers, etc. for the presence of zebra mussels, and to disseminate information which states that it is illegal under the provisions of the Lacy Act to transport zebra mussels into or out of the United States. It is also important that all Federal agencies comply with the intent of the Lacy Act, i.e., not to allow activities that would result in the proliferation or transport of injurious species.

State Laws - Many States already have laws that apply to zebra mussels. State laws regulate the taking and transport of fish & game, and regulate fishing and aquaculture by issuing permits, licenses and proclamations. In addition, State laws also regulate agricultural products and nuisance species which affect agricultural production.

Federal, state, and private fish hatcheries are inspected to determine if certain pathogens are present. It will be necessary to monitor for the presence of zebra mussels and to include zebra mussels on the list of species to be excluded at all fish-rearing facilities. A certification of "zebra mussel free" status should be required before fish from these facilities can be placed into uninfected areas. It would also seem prudent to quarantine all shipments of aquatic species received in hatcheries that come from infected regions of the country. These shipments should be inspected for zebra mussels (and perhaps other species) and destroyed if necessary.

PARTNERSHIPS

An effective prevention program will require a carefully coordinated effort to limit or prevent further spread of zebra mussels into the West. The effort would be strengthened by the development of partnerships. If the Service and others are to launch an effective program, individuals and agencies must be encouraged to take ownership in preventing the import of zebra mussels into their area. The formation of joint ventures should be promoted between the Service and people from groups such as Project Wild, Riverwatch, and others. The Service could facilitate action by providing funding, talent, guidance, and equipment. Existing MOU's could be utilized. Localized zebra mussel prevention partnership programs such as the St. Croix Conservation Partnership may be effective in keeping zebra mussels out of some watersheds.

CONCLUSIONS

- Spread of the zebra mussel has occurred so rapidly in the eastern United States that it has been difficult for agencies to develop prevention programs before the mussel became established. Thus, there has been much work done on control, but little on prevention.

- It is assumed that zebra mussels should not spread as quickly into the western, more arid region of the United States as it has in the eastern United States. The rapid downstream colonization of the zebra mussel from the Great Lakes and transport of the mussel into upstream areas by commercial barge traffic was predictable due to interconnecting waterways. On the other hand, conditions in the more arid west such as upstream gradients, and the requirement for overland transport of the species, may provide the opportunity to stop further western expansion of the zebra mussel. If so, the zebra mussel may be contained to the eastern United States for an indefinite period. However, if the mussel crosses the Continental Divide and invades the headwaters of large Western rivers (e.g., the Columbia River drainage) it may quickly colonize huge areas of the Western United States.

- Critics may scoff at the idea that stopping further zebra mussel expansion is possible, however, long distances, arid climates, and upstream gradients may make it more difficult to spread zebra mussels into Western environments than in the East.

- Once spread to the Western United States, zebra mussels will presumably create massive water development and environmental problems. If zebra mussels find their way into the thousands of miles of large

irrigation and other water canal systems of the Bureau of Reclamation and other agencies, they may be spread at a rapid rate.

- Economic costs associated with the introduction of the zebra mussel into large Western water projects will be high. Slowing its rate of invasion could save millions and perhaps billions of dollars.

- Economic benefits associated with slowing the invasion of the zebra mussel will accrue from providing the time to retrofit municipal, industrial, and governmental water resources development projects so they can function with zebra mussel infestations.

- Environmental benefits associated with stopping the spread of the zebra mussel into some sensitive Western habitats are more difficult to assess. The zebra mussel may change some systems to the extent that listed species (especially native mussels) may become extirpated, populations of some species reduced, and other species endangered.

- If existing laws, regulations and permits are utilized in an effective manner, zebra mussel invasions can be slowed and perhaps prevented in some areas. Public involvement could also provide substantial assistance in combatting the spread of the zebra mussel.

- Every effort should be made to slow or stop the spread of the zebra mussel into the Western United States, but control methods should also be further developed and used to remove populations where feasible.

- The development of a program to prevent the spread of zebra mussels in the West could also focus attention on, and could result in the establishment of similar programs for all nonindigenous species.

RECOMMENDATIONS

It is recommended that the Service identify and fund Nonindigenous Species/Zebra Mussel coordinator positions in Regions 1, 2, and 6. Coordinators should be senior staff, and have the authority to represent Regional Directors in making the necessary contacts with States and other agencies for the purpose of encouraging the establishment of State nonindigenous species programs. It is suggested that these coordinators be in such positions as to interact freely between various divisions in the Regions, including Fisheries, Federal Aid, Ecological Services, Endangered Species, Refuges, Law Enforcement, Public Affairs, and others. (Note: The need for regional Service coordinators to assist in preventing and controlling zebra mussels has previously been identified in an earlier Service study (Hendrix et al. 1993).

Acting through these coordinators, the Service should quickly develop and implement an action plan to prevent the further western invasion of the zebra mussel and to prevent it from crossing the Continental Divide. The following objectives should be considered for preventing the spread of zebra mussels:

1. To develop an I & E program for nonindigenous species and encourage States and other agencies to develop such programs;

2. To enforce provisions of the Lacy Act and other applicable Federal and State statutes at the Canadian Border and other borders as appropriate;

3. To contact State and Provincial governments and other Federal and private agencies, and encourage them to become active participants in slowing or stopping further invasion of the zebra mussel by utilizing existing statutes or enacting new laws;

4. To support, and work to convince other Federal, State and local governments, and others, of the importance of an uncontaminated buffer zone between the Continental Divide and contaminated Eastern areas;

5. To encourage individual States and Canada to assess their capabilities to establish inspection stations to reduce the transport of zebra mussels and work with these governments to assist them in this endeavor;

6. To evaluate the potential impact of the zebra mussel on Western ecosystems, including native freshwater mussels and other species that may become endangered because of the zebra mussel;

7. To develop and implement a Service action plan that identifies roles and responsibilities for short and long-term Service involvement. In addition, the Service should develop more specific guidelines and/or policies regarding the transport of zebra mussels. As a minimum, the following practices should be implemented:

   a. Hatcheries that transport fish into uninfected areas should be inspected to determine zebra mussel status just as they are required to be inspected to determine disease status.

   b. Fish or water should not be shipped nor received from contaminated areas unless certified free of zebra mussels.

   c. Provisions of the Lacy Act and other existing authorities and their intent should be supported and actively enforced by refusing to provide Federal Aid funds to any State program that may result in the spread of zebra mussels.

   d. Partnerships with others should be instituted and more interactive programs that are modelled after the St. Croix Conservation Partnership, or similar programs, should be developed.

   e. The Service should expedite the final signing of the Draft MOU with the Bureau of Reclamation and seek to broaden this MOU as it suggests. New MOU's or agreements should be developed with other agencies and groups as deemed prudent.

8. To identify facilities and environments at risk to zebra mussel infestation by working with State and other Federal Agencies. Watershed plans should be developed and measures to prevent zebra mussel invasion in areas at risk should be determined and implemented.

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